Realistic and Real-Time Deformable Organ Simulation

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We present a computational framework for *realistic* and *real-time* simulation of the *structure* and *behavior* of complex deformable organs. For structure simulation, our method utilizes the Visible Human Dataset to construct anatomically-detailed, and visually-realistic template organ models. For behavior simulation, our method exploits a boundary-based simulation paradigm (the boundary element methods or BEM), which concentrates computation on the visible surfaces of the organ. The BEM enjoys the advantage of not having to discretize the internal organ structure, while still able to simulate interesting and physically-meaningful global material properties (e.g., rigidity and compressibility) faithfully.

While BEM-based organ simulation has been reported before (e.g., ArtDefo by James and Pai), our contribution is in utilizing a numerical method that is not only fast, but is also much more flexible in handling the ever-changing boundary conditions in the simulation of organ deformation. ArtDefo allows the boundary conditions to change in a way that only a few columns in the coefficient matrix are altered in a predictable manner (e.g., moving the tip of an instrument across the surface of an organ). If that is true, a low-rank update formula due to Sherman-Morrison-Woodbury can be applied to enable fast on-line modification to small parts of the coefficient matrix. Hence, a large portion of the coefficient matrix can be pre-computed off-line to improve efficiency. While such an approach is sensible, it does restrict the type of collision an organ can experience in simulation. In cramped body cavities (such as the abdominal cavity), low-rank update is generally not a valid assumption.

On the other hand, our numeric algorithm exploits a different mechanism to reduce update complexity. Our observation is that the kernel function in the fundamental solution of the BEM is usually smooth, which results in the coefficient matrix having a block-wise low-rank structure, which we called sequentially semi-separable (SSS) for the one-dimensional case, and hierarchically semi-separable (HSS) for higher dimensions. Exploiting this particular matrix structure in our simulation, we are able to achieve real-time behavior simulation on ordinary PC of fairly complex organs. Our simulation allows large changes in boundary conditions, such as those resulted from organ-organ collision and organ-abdominal wall collision, which is not possible in ArtDefo. We will provide a live demo at the Symposium to demonstrate our software system.